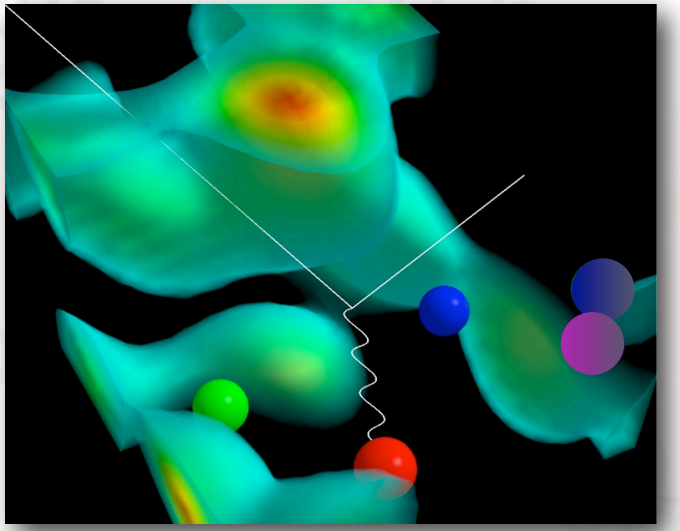
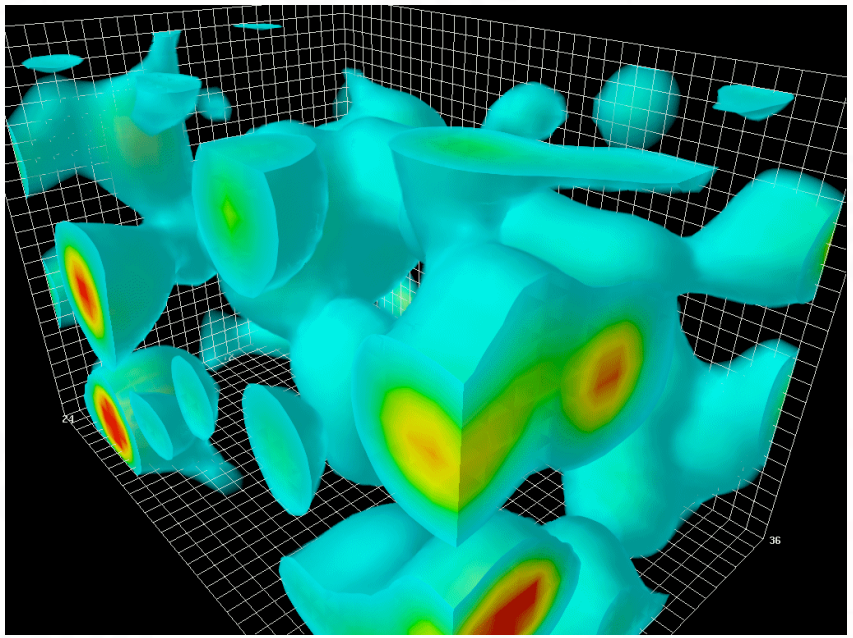
Experimental aspects on Low-x Physics at a Future EIC facility
- Concepts / Status / Projections -

Bernd Surrow

TEMPLE UNIVERSITY



Motivation



(D. Leinweber: Action (~energy) density fluctuations of gluon-fields in QCD vacuum)

Structure and dynamics of proton (**mass / spin**) (→ visible universe) originates from QCD-interactions!

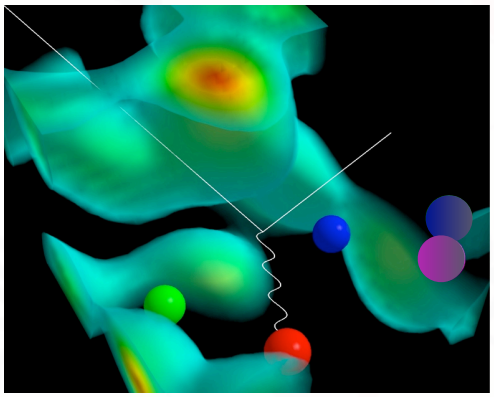
Synergy of experimental progress and theory (Lattice QCD / Phenomenology incl. phenomenological fits / Modeling) critical!

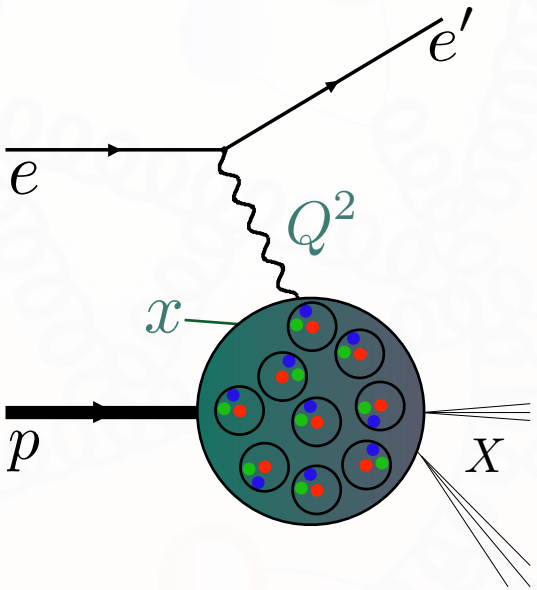
Motivation

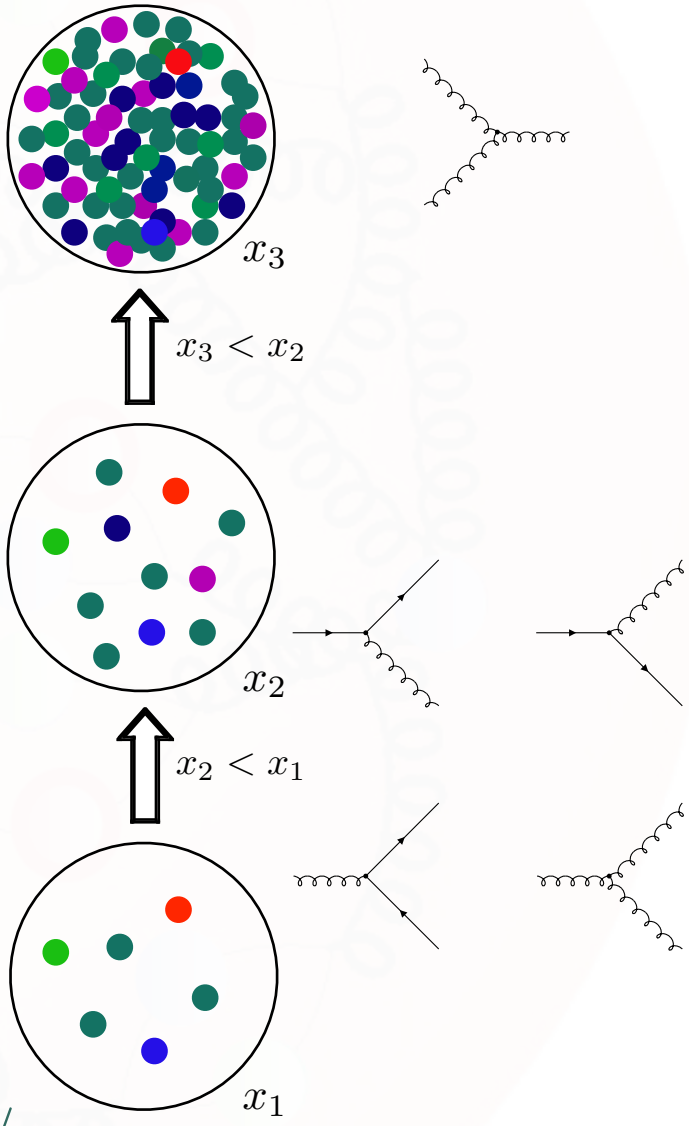
- The silent (low x) partners…: Gluons and QCD-Sea

Fundamental questions:

- What are the properties of gluons that bind strongly interacting particles?
- What is the quark-gluon internal structure of nucleons?
- What are the properties of quark-gluon matter at high density?



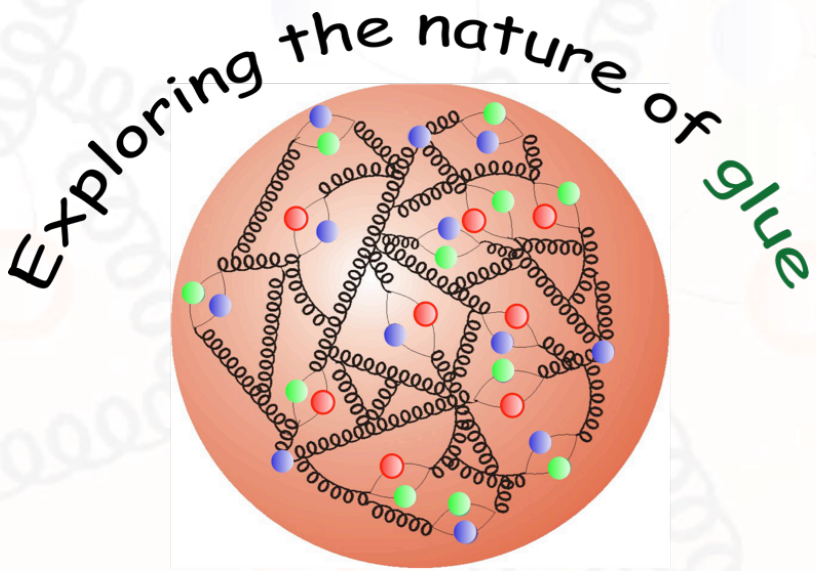




Outline

- Future unpolarized low-x opportunities:

  Unpolarized ep/eA physics



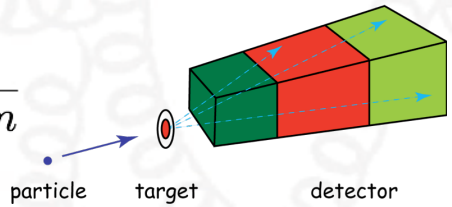
- Concepts and Status
- Summary and Outlook

Concepts and Status

- Low-x kinematics
  - Access higher parton density system
    - Larger center-of-mass energy (√s): Smaller x at larger √s!

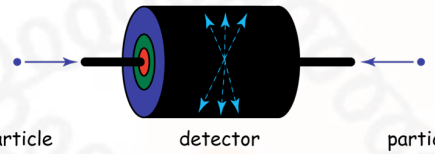
fixed-target

$\sqrt{s} = \sqrt{2E_B m}$



$x \sim \frac{Q^2}{s}$

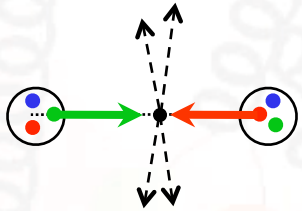
collider



$\sqrt{s} = \sqrt{4E_{b_1}E_{b_2}}$

- Forward direction: Smaller x at larger η!

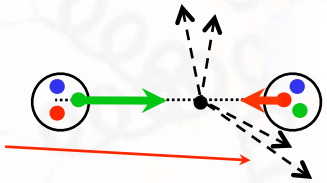
central
(η ≈ 0)



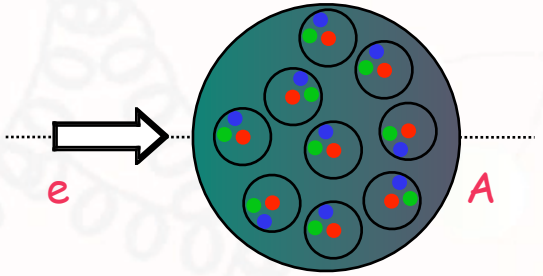
$x \sim \frac{2p_T}{\sqrt{s}} e^{-\eta}$

(η ≈ 0)

forward
(η large)



- eA vs. ep scattering: Probe higher parton density system in eA compared to ep!



$\sim A^{1/3}$

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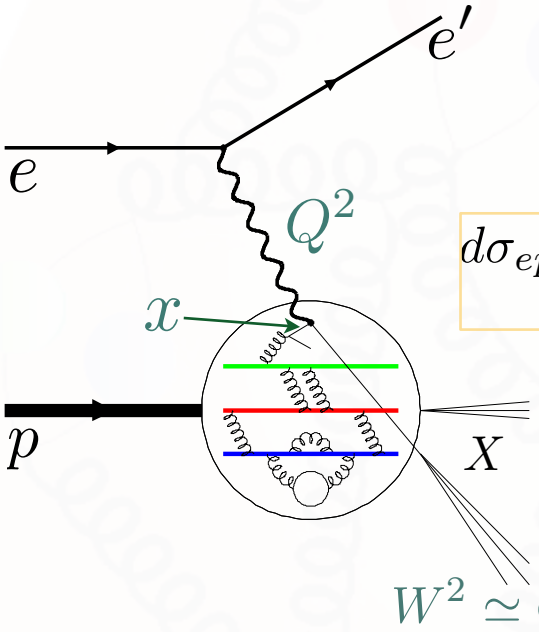
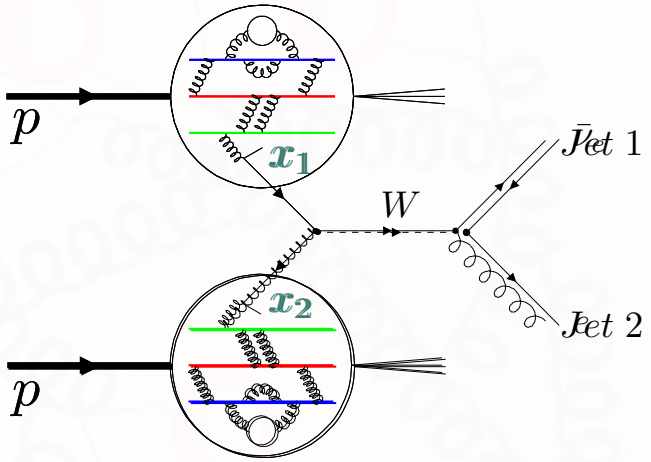
Concepts and Status

- Probing the structure and dynamics of matter in ep vs. pp scattering



$$d\sigma_{ep} \propto F_2 = \sum_q x e_q^2 f_q(x)$$

Universality



$$d\sigma_{pp} \propto f_1 \otimes f_2 \otimes \sigma_h \otimes D_f^h$$ Factorization

Momentum contribution

$$f(x) =$$

$$f^+(x) + f^-(x)$$

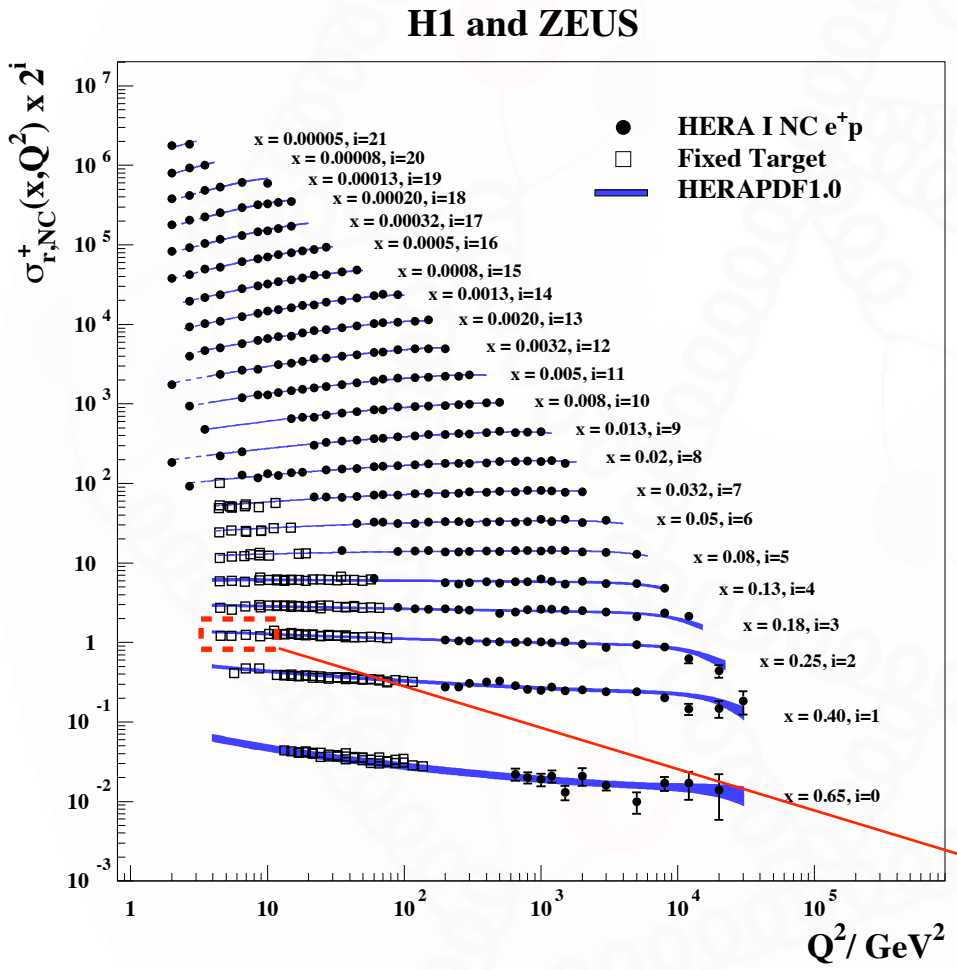
$$\Delta f(x) =$$

$$f^+(x) - f^-(x)$$

Spin contribution

Concepts and Status

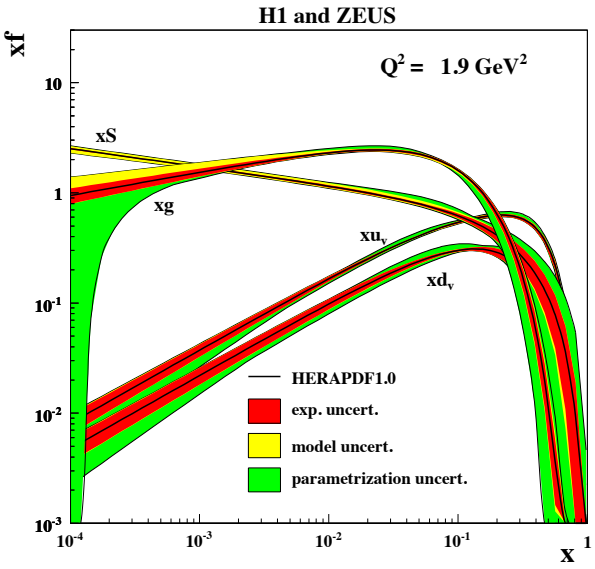
- Picture of the proton from unpolarized ep scattering

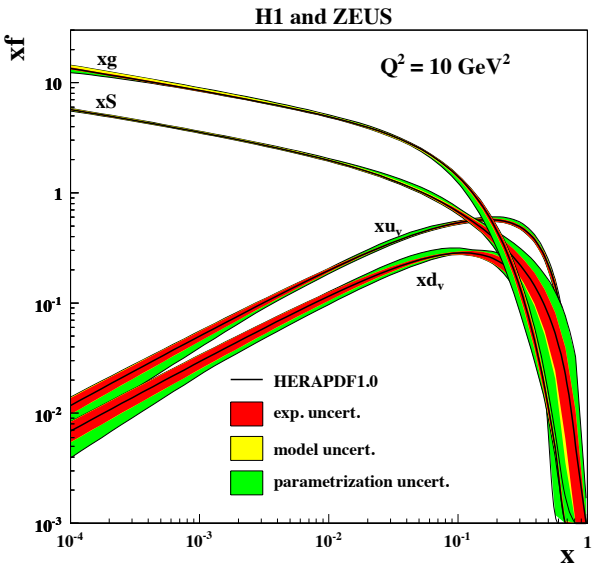


Strong violation of scaling at low x and high Q^2

In contrast to:

Low Q^2 high x!



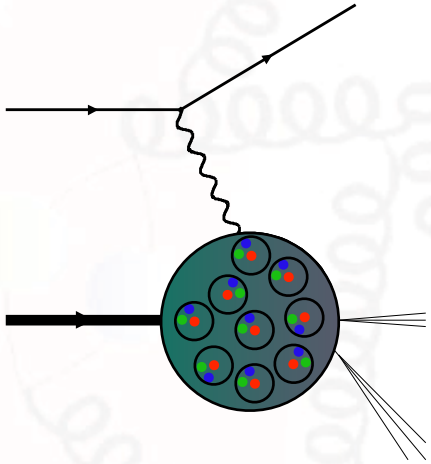


- Huge gluon and QCD sea contribution!

Concepts and Status

- Probing the structure and dynamics of matter in eA / pA scattering

$$Y_+ = 1 + (1-y)^2$$

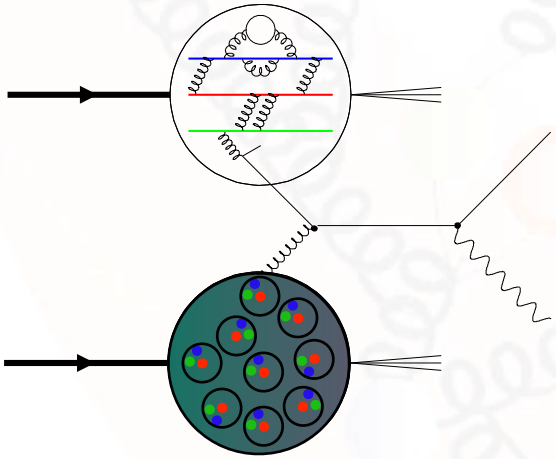


$$\left(\frac{d^2\sigma}{dydQ^2}\right) = \frac{2\pi\alpha^2 Y_+}{yQ^4}\left(F_2 - \frac{y^2}{Y_+}F_L\right)$$

$$\sigma_{tot}^{\gamma^* p} = \sigma_T^{\gamma^* p} + \sigma_L^{\gamma^* p}$$

$$F_2 = \frac{Q^2}{4\pi^2\alpha}\sigma_{tot}^{\gamma^* p} = \sum_{f=q\bar{q}} x e_q^2 f \qquad F_L = \frac{Q^2}{4\pi^2\alpha}\sigma_L^{\gamma^* p} \propto xg$$

Universality



$$d\sigma = \sum_{f_1,f_2} f_1 \otimes f_2 \otimes d\hat{\sigma}^{f_1 f_2 \to f X} \otimes D_f^h$$

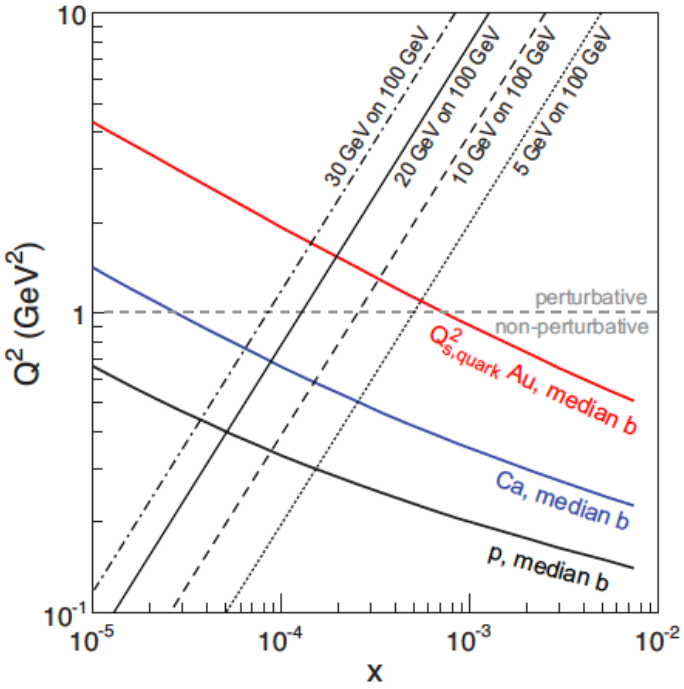
Factorization

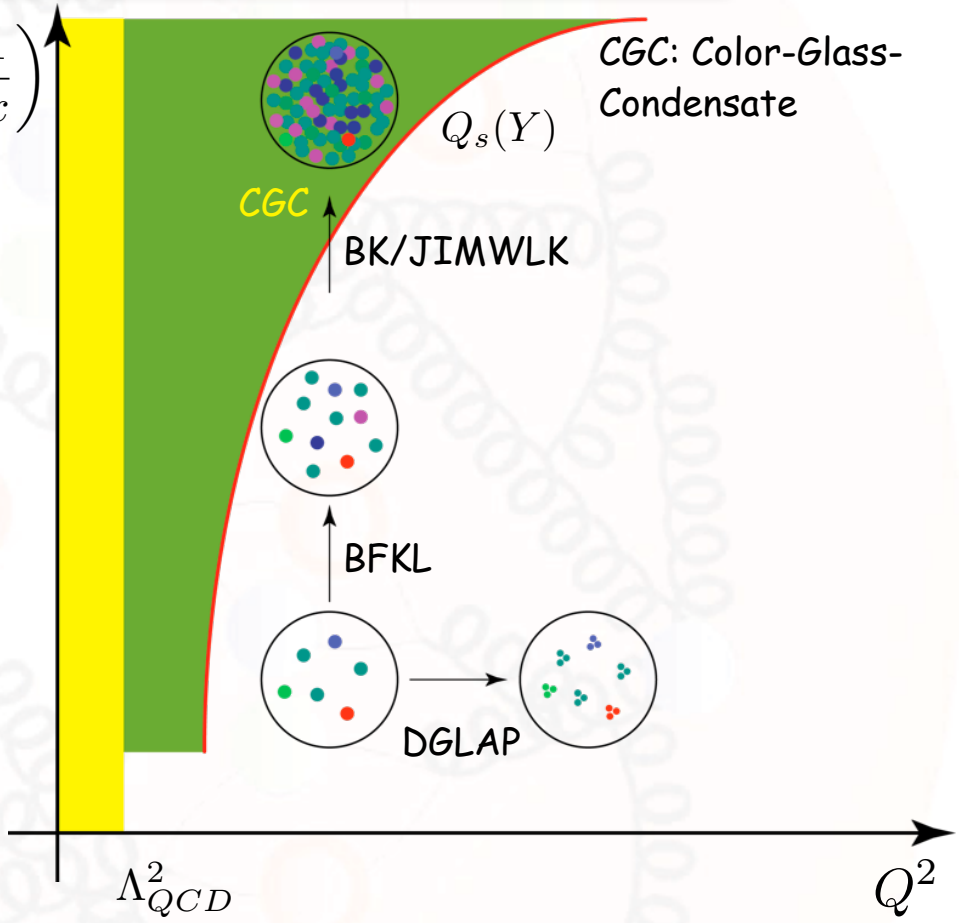
Important: Complementary probes are required for unambiguous extraction of observables in high-energy density QCD region!

Concepts and Status

- Low-x basics (1)
  - Dynamics: DGLAP / BFKL and CGC

$$Y = \ln\left(\frac{1}{x}\right)$$





Q_s^2: Saturation scale ⇒ Characterize transition to saturation region!

$$Q_s^2 \simeq \alpha_s \frac{1}{\pi R^2} x G(x, Q^2) \sim$$

Enhanced for eA compared to ep: $A^{1/3} x^{-\delta}$

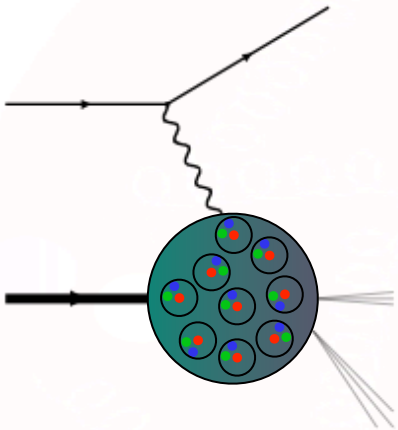
$\alpha_s \sim 1$ $\qquad$ $\alpha_s \ll 1$

$$Q^2 > Q_s^2 \Rightarrow \alpha_s = \alpha_s(Q^2)$$

$$Q^2 < Q_s^2 \Rightarrow \alpha_s = \alpha_s(Q_s^2)$$

Concepts and Status

- Low-x basics (2)
  - Dipole model



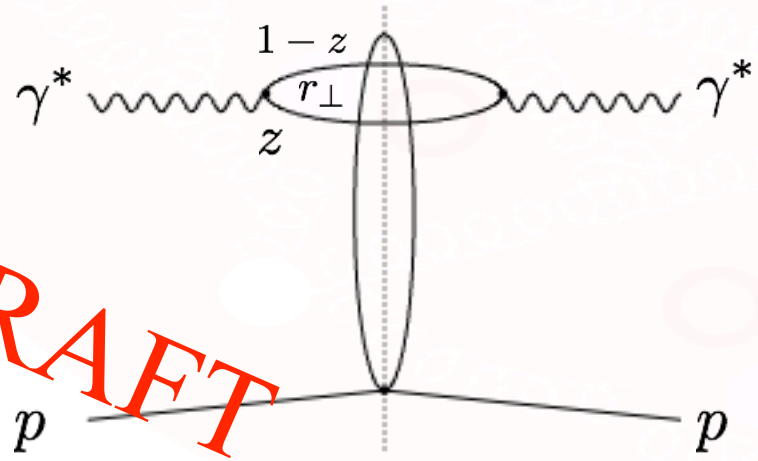
Consider virtual photon-proton cross-section

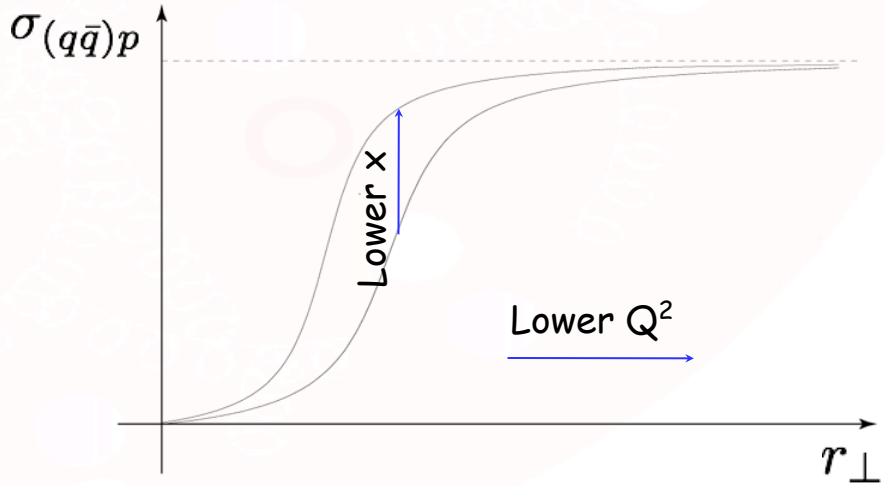
Frame: Proton rest frame

Interaction time < Fluctuation time at low x

Dipole model: Interaction of quark/anti-quark pair with proton

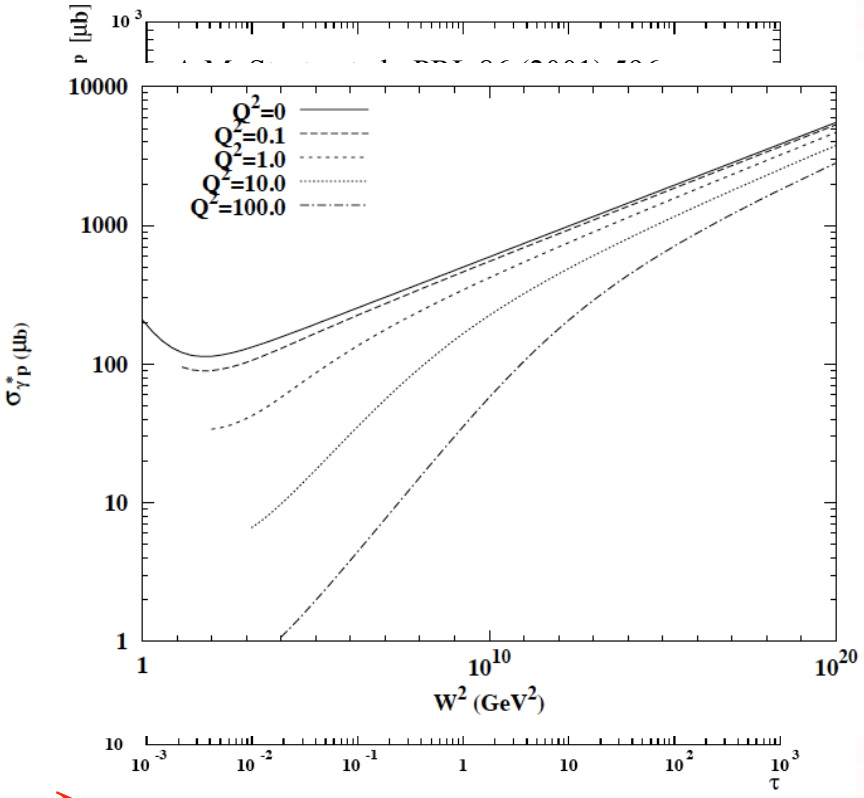
$$\sigma_{tot}^{\gamma^* p} = \int dz \int d_{r_\perp}^2 |\Psi|^2 \sigma_{(q\bar{q})p}$$

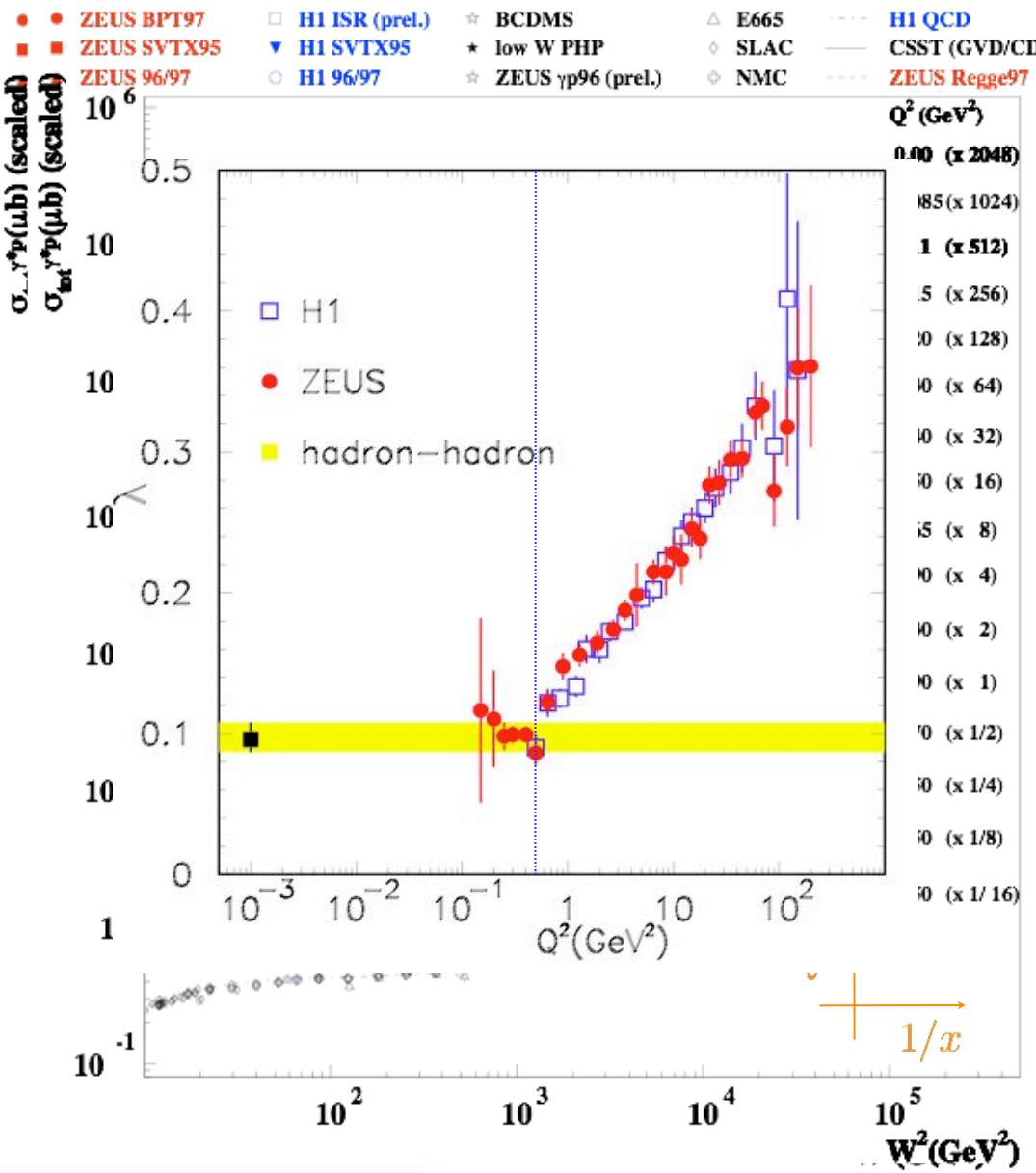




Concepts and Status

- HERA: $\gamma^* p$ cross-section





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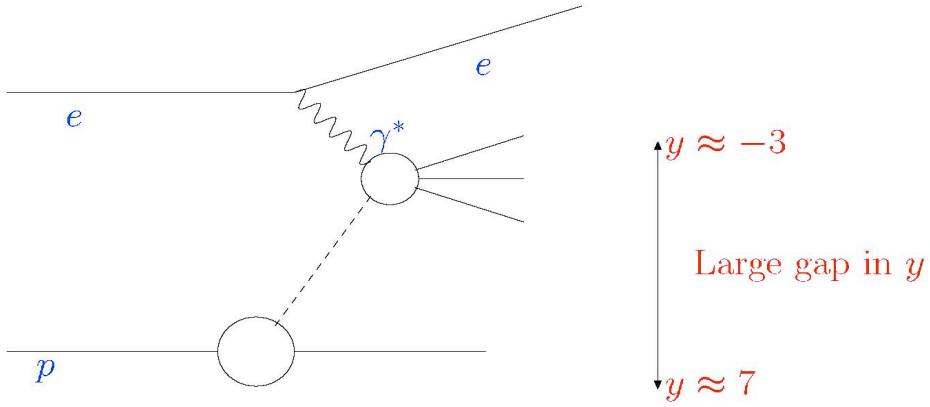
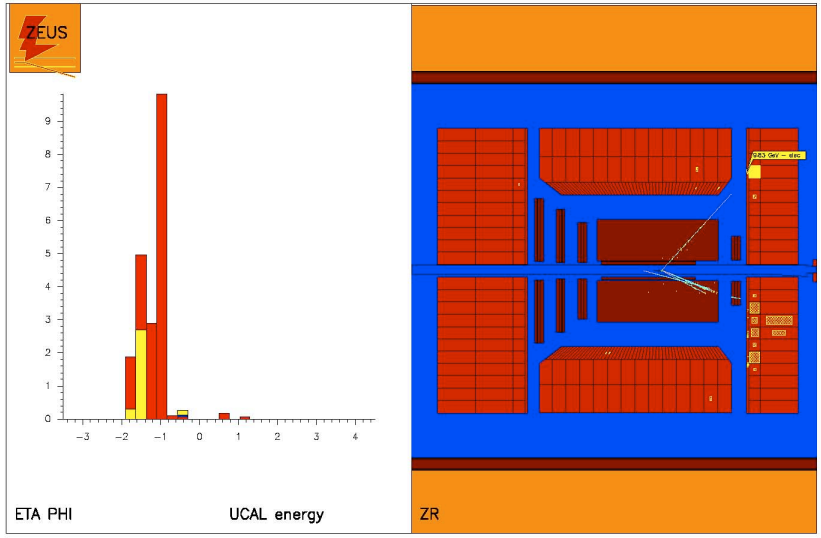
- Dipole-model approach: Successful description of both inclusive and diffractive processes at low x
- Change of Q^2 dependence around 1GeV^2!

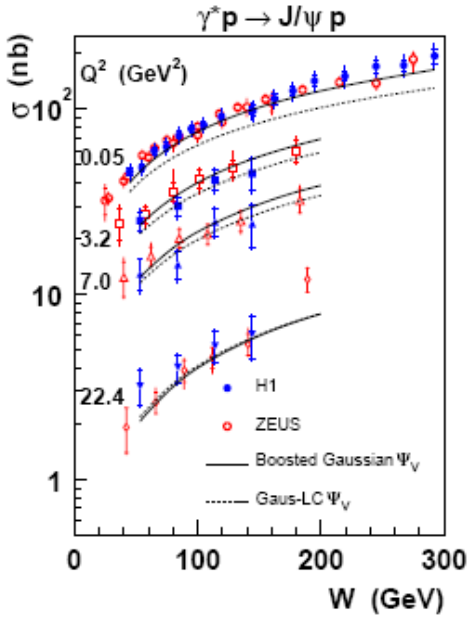
Concepts and Status

- Diffraction





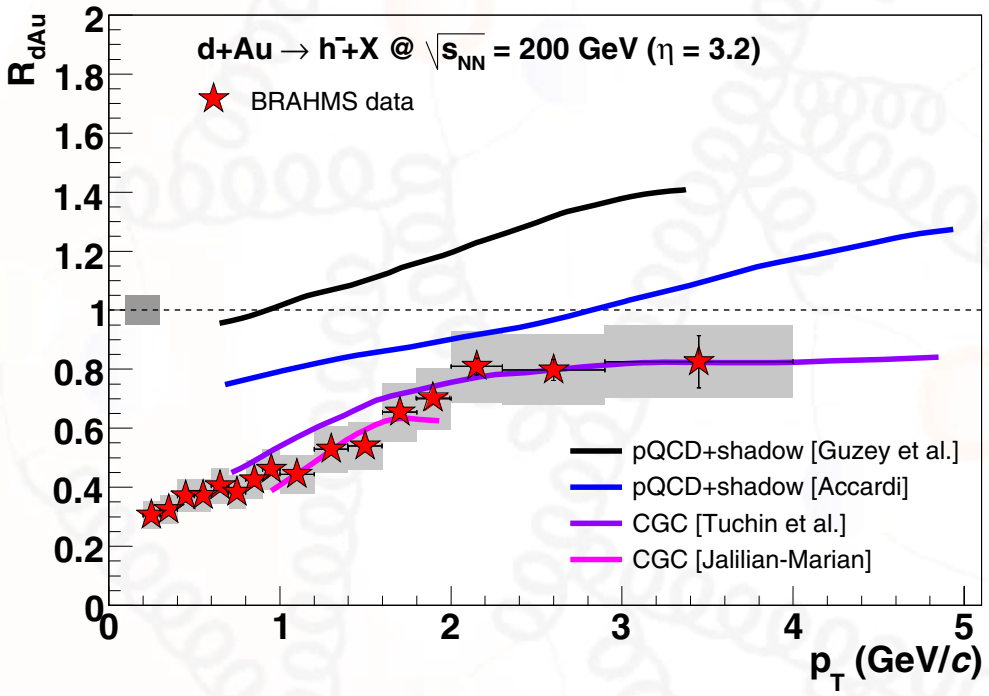
- Ratio of diffractive to total cross-section (200<W<245GeV): 15% at Q^2=4GeV^2
- Dipole models: Successful description of inclusive and various diffractive measurements (e.g. Ratio of diffractive to inclusive cross-section, Diffractive Vector-Meson production)

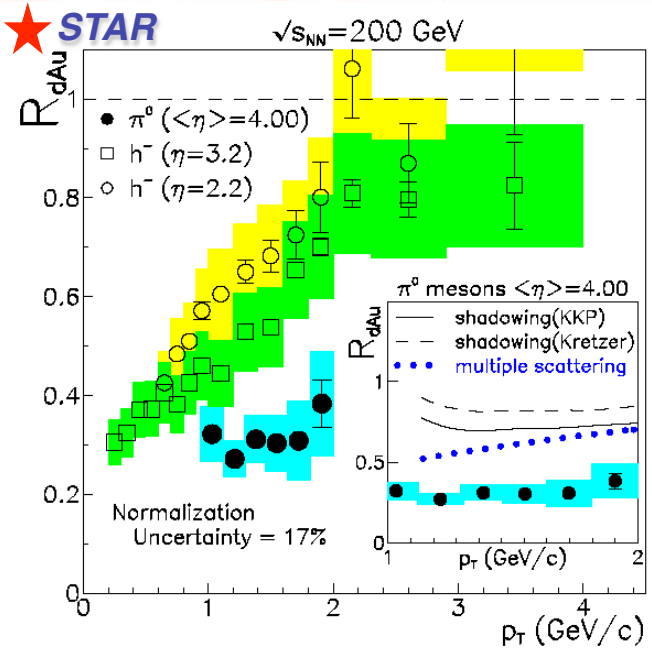


$$\propto \alpha_s^2 \left[g(x, Q^2)\right]^2$$

Concepts and Status

- RHIC dA scattering at forward η





- Forward identified hadron production at RHIC in dAu collisions: Sizable suppression of yields for charged hadrons and neutral pions observed
- pQCD+shadowing calculations over-predict hadron yield suppression. Is this an indication for gluon saturation in Au nuclei?
- More RHIC dAu are expected with enhanced detector capabilities (PHENIX/STAR)

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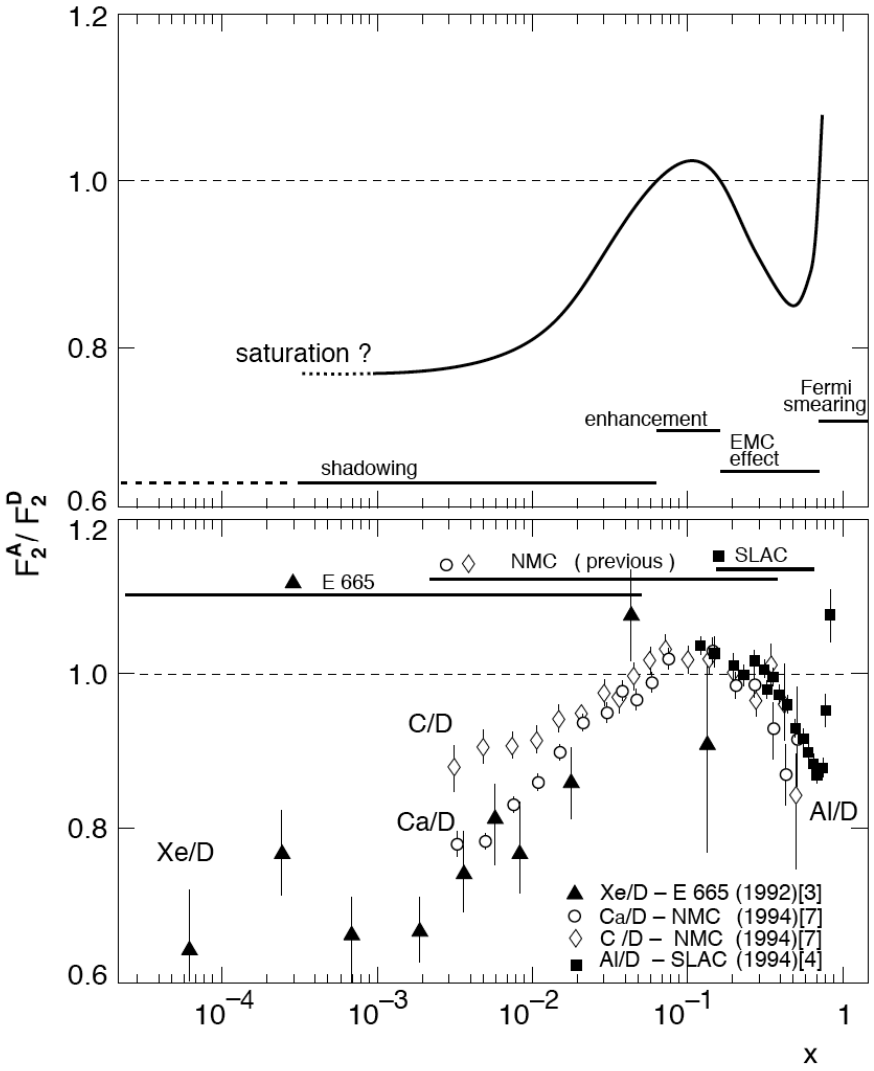
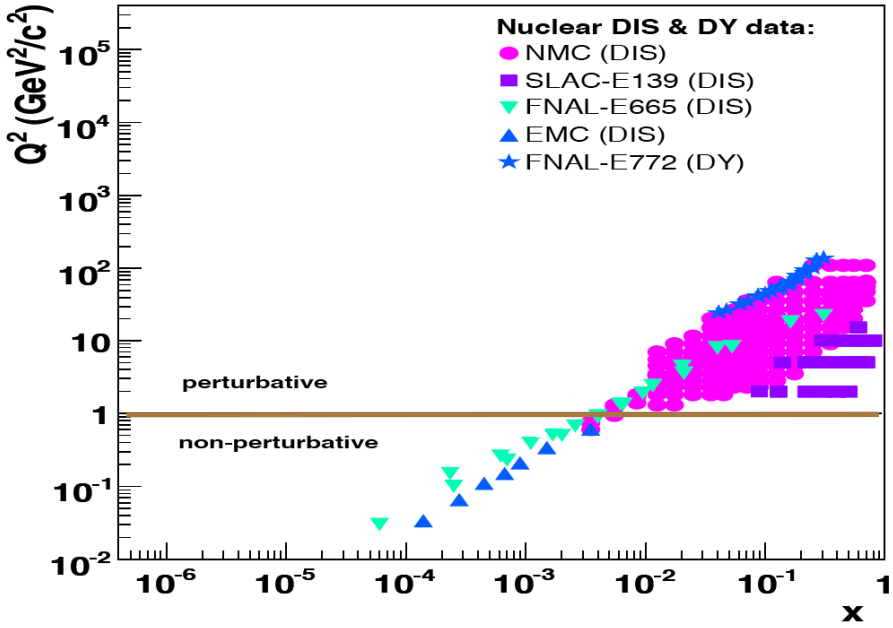
Concepts and Status

- Fixed-target scattering experiments





- Inclusive structure function ratio important to constrain nuclear modifications to gluon density
- World data (Fixed target) are concentrated above x>0.01 in pQCD region
- For x<0.01 only data in non-pQCD region

Future opportunities

- EIC facilities

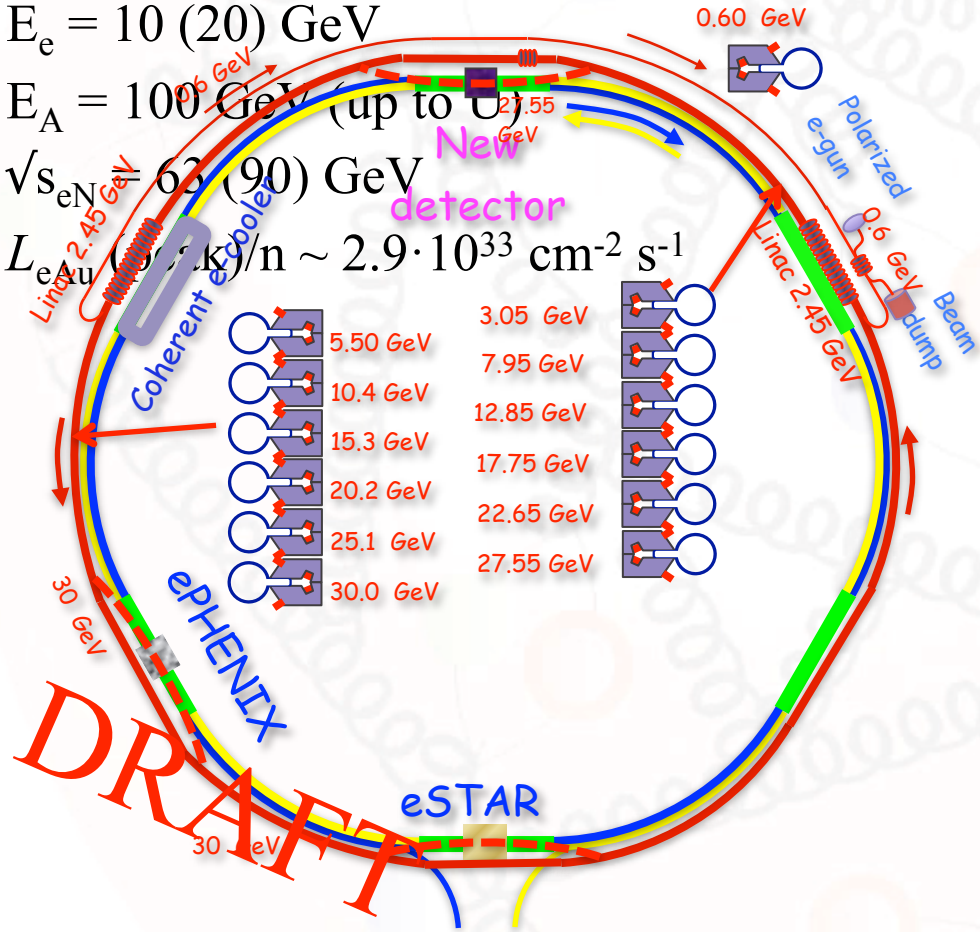
eRHIC (BNL)

$E_e = 10\ (20)$ GeV

$E_A = 100$ GeV (up to U)

$\sqrt{s_{eN}} = 63\ (90)$ GeV

L_{eAu} (peak)/n ~ $2.9 \cdot 10^{33}$ cm^{-2} s^{-1}



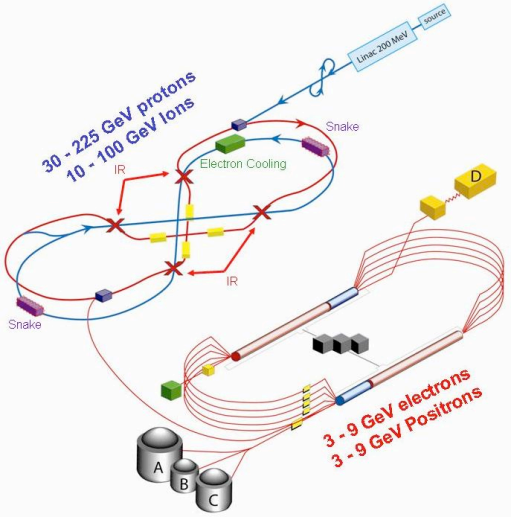
ELIC (JLAB)

$E_e = 9$ GeV

$E_A = 90$ GeV (up to Au)

$\sqrt{s_{eN}} = 57$ GeV

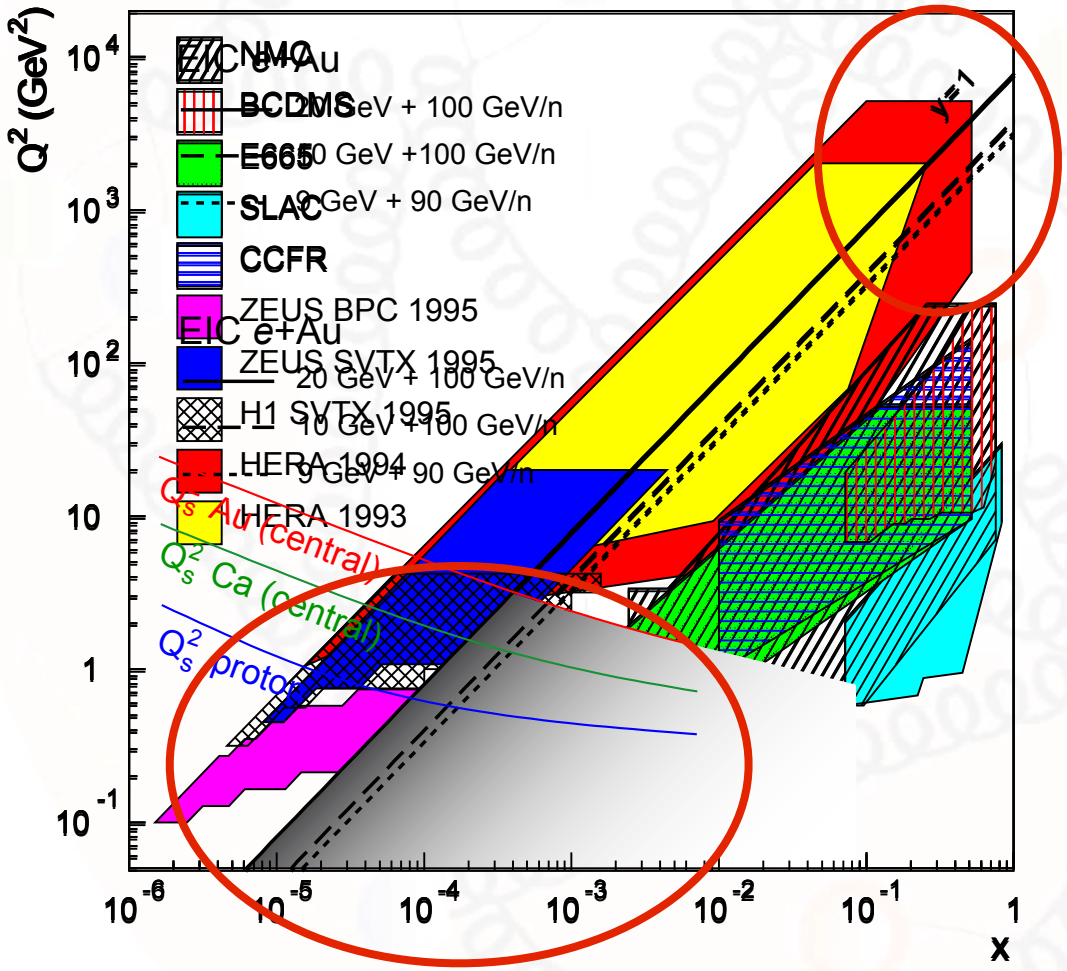
L_{eAu} (peak)/n ~ $1.6 \cdot 10^{35}$ cm^{-2} s^{-1}

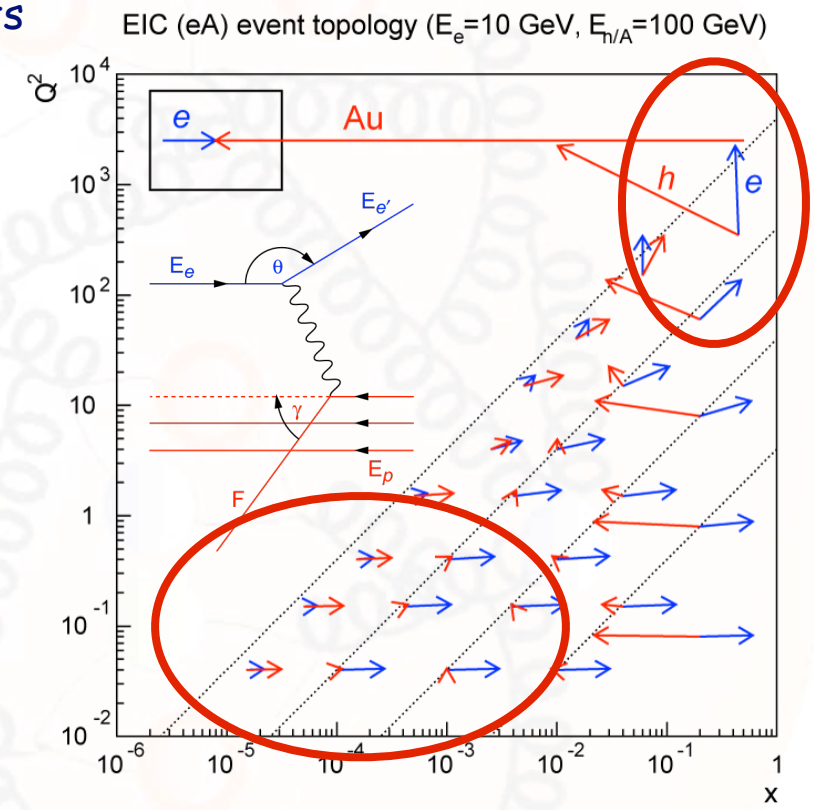


EL...

Future Opportunities

- Kinematics
  - Comparison HERA / EIC / Fixed-target experiments





Terra incognita:

small-x, $Q \approx Q_s$

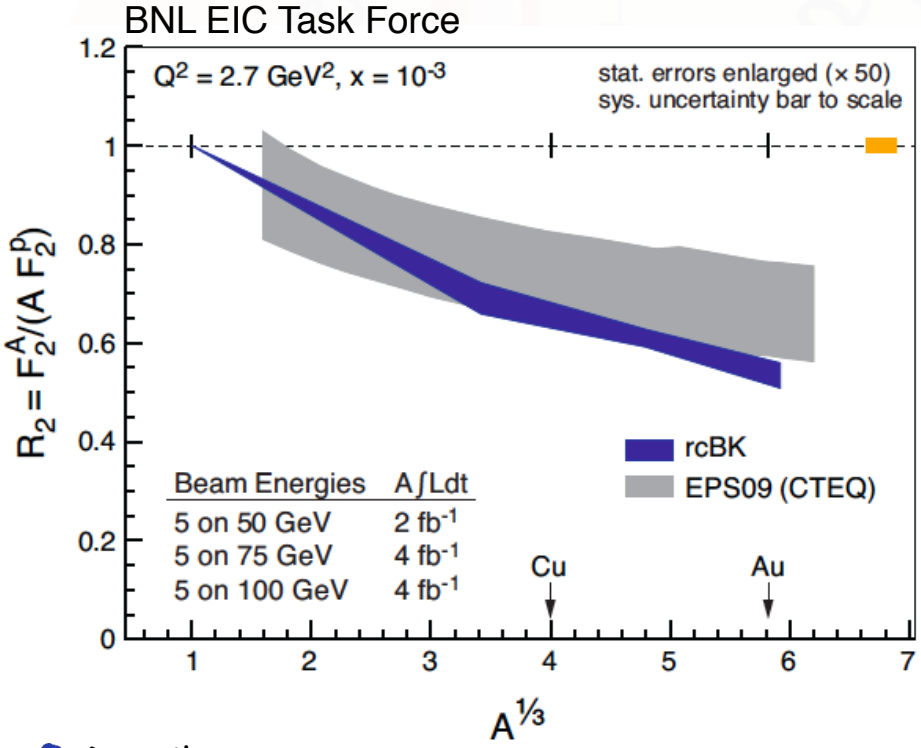
high-x, large Q^2

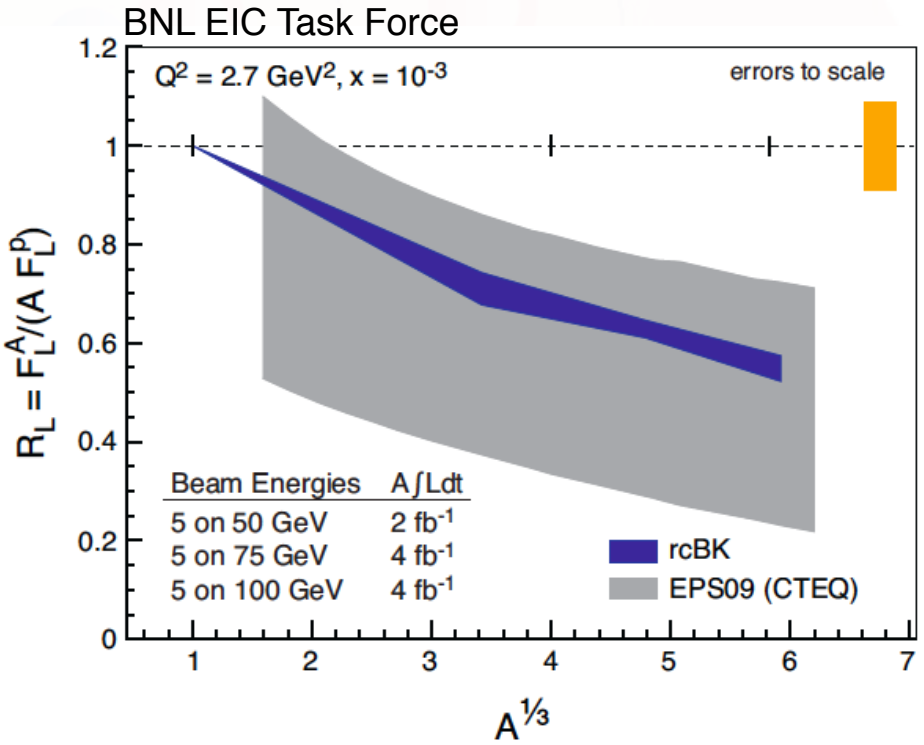
Future Opportunities

- Key observables in electron-proton and electron-nucleus scattering
  - Gluon distribution:
    - F_L (Variable center-of-mass energy) and F_2
    - Jet rates
    - Inelastic vector meson production (e.g. J/Psi)
  - Space-Time distribution of gluon:
    - F_L (Variable center-of-mass energy) and F_2
    - Deep virtual compton scattering (DVCS)
    - Exclusive final states (e.g. Vector meson production)
  - Interaction of fast probes with matter:
    - Hadronization, Fragmentation studies
    - Energy loss (Heavy quarks)
  - Impact of strong gluon fields on the role of color neutral excitations:
    - Diffractive structure functions
    - Diffractive vector meson production

Future Opportunities: Unpolarized eA physics

- F^A_2 ratio at EIC vs. $A^{1/3}$





- Details

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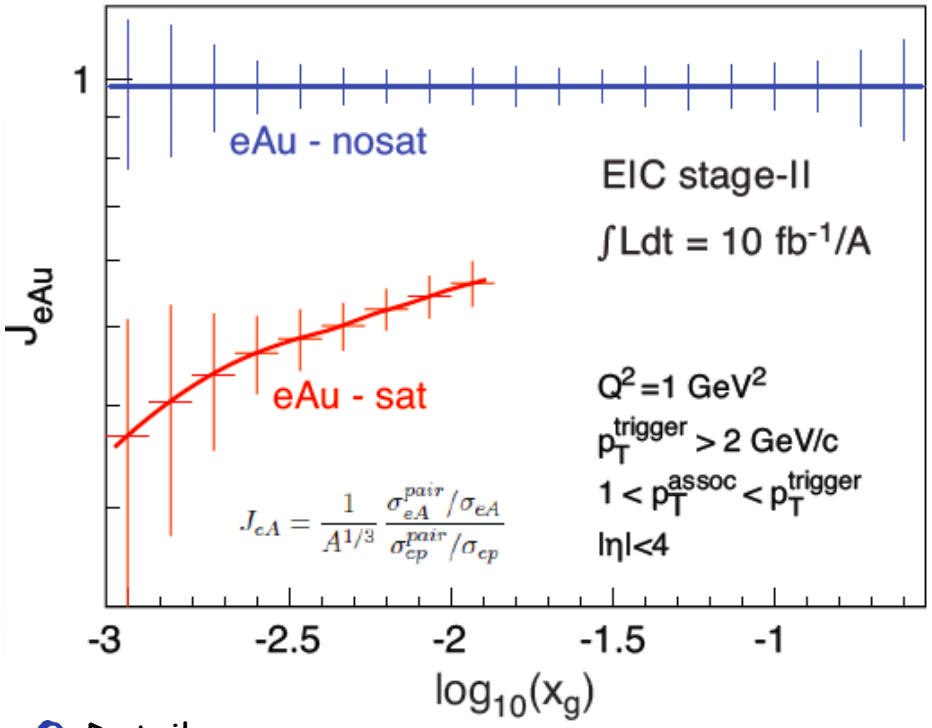
Future Opportunities: Unpolarized eA physics

- Di-hadron correlation vs. x at EIC: Nuclear modification J_{eAu}

BNL EIC Task Force



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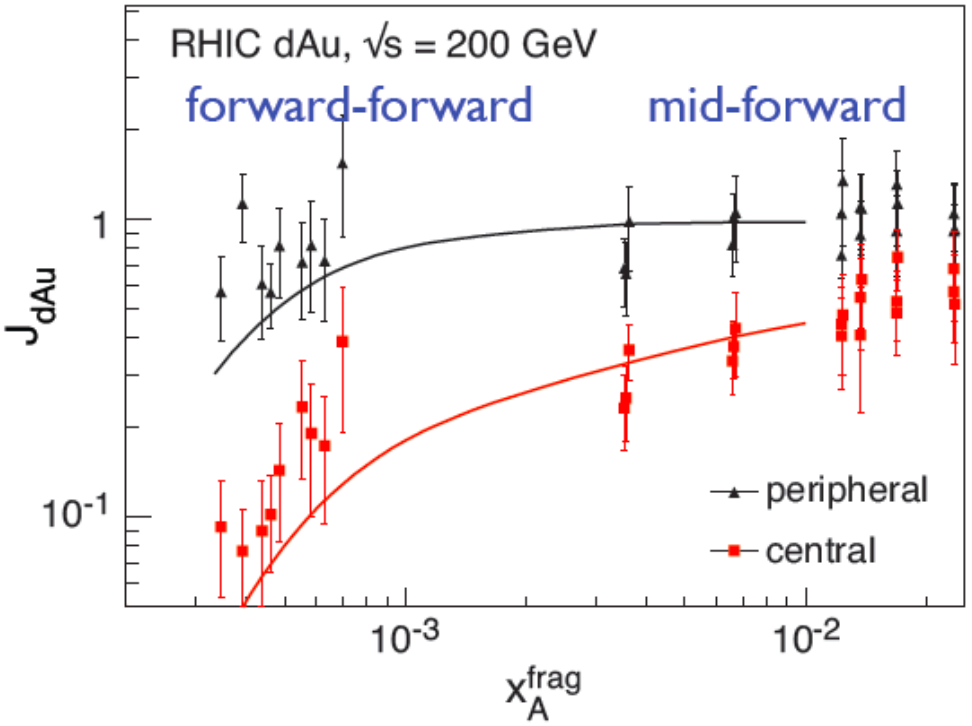

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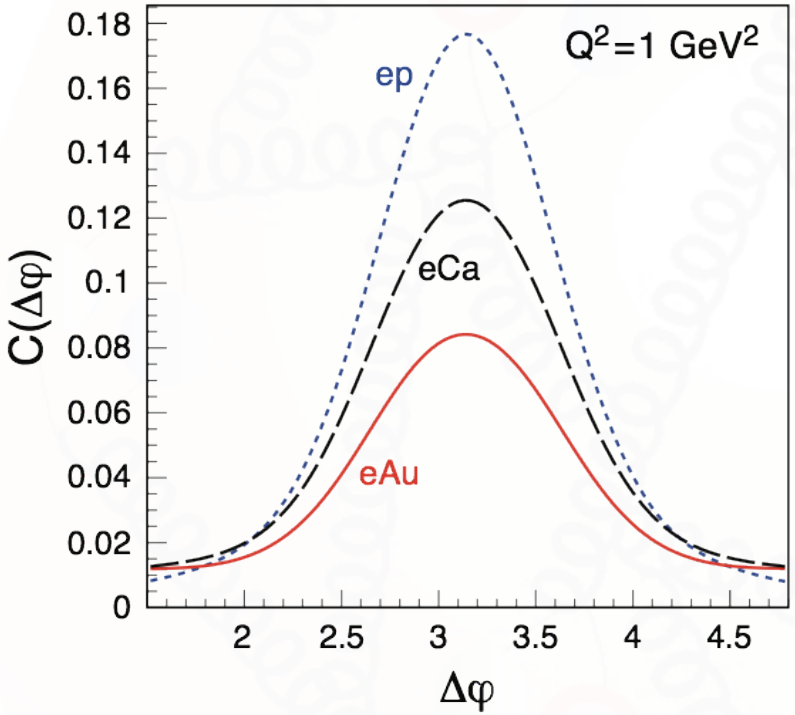
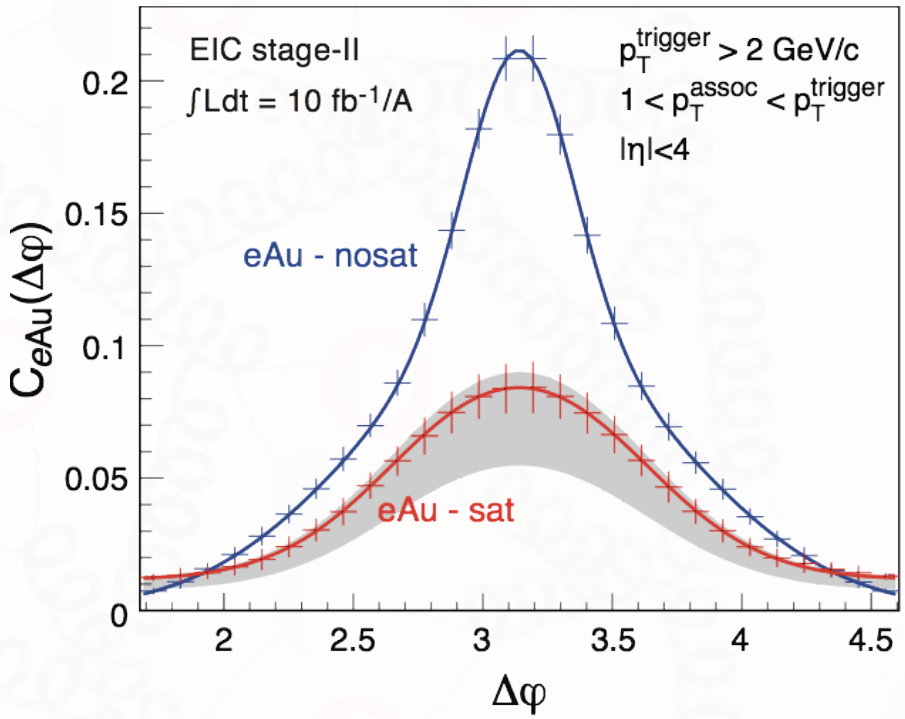
Future Opportunities: Unpolarized eA physics

- Di-hadron correlation at EIC

BNL EIC Task Force



BNL EIC Task Force



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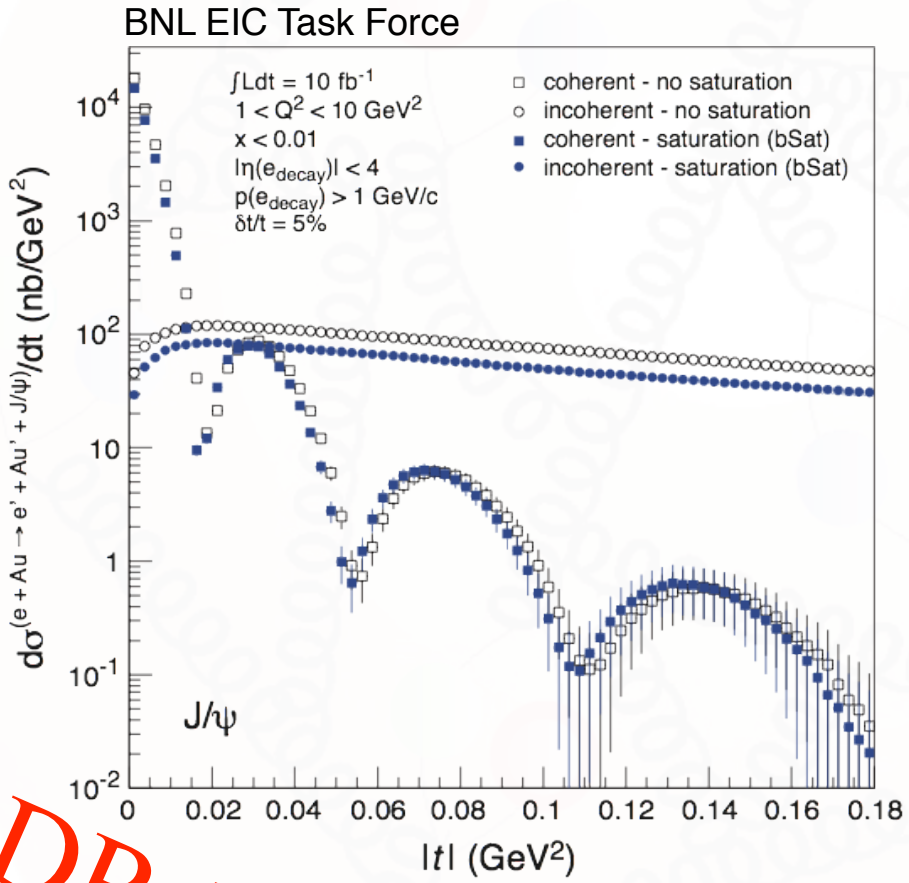
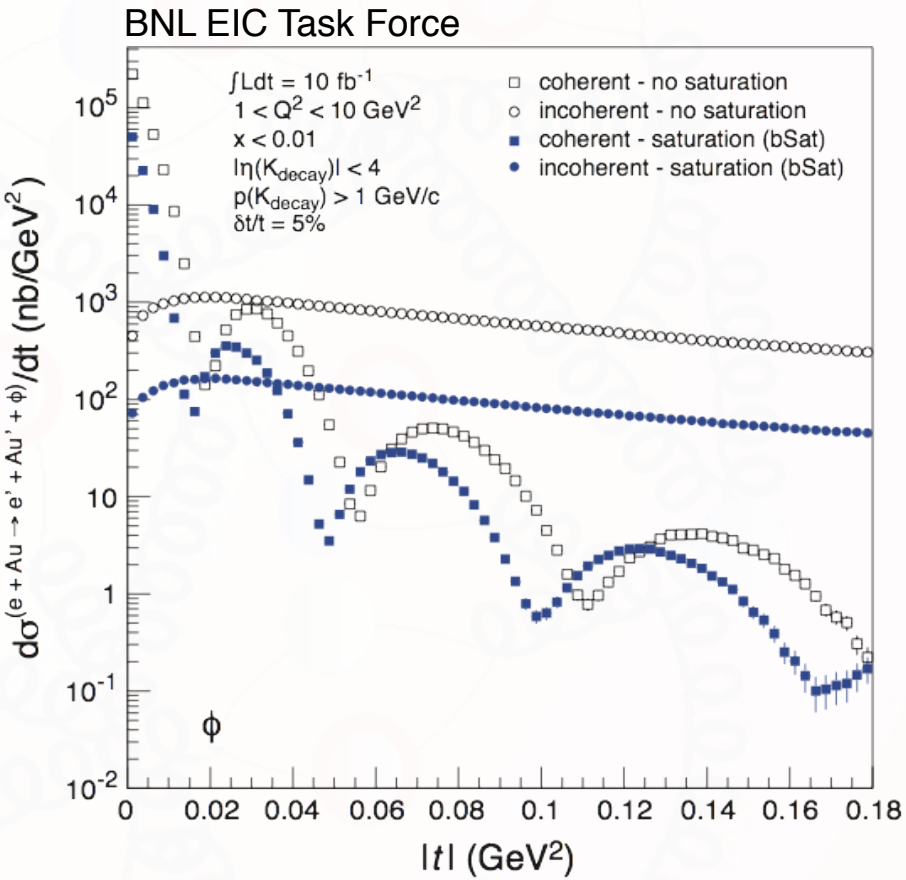
Future Opportunities: Unpolarized eA physics

- Diffractive VM production at EIC: J/Ψ and Φ (1)





- Details

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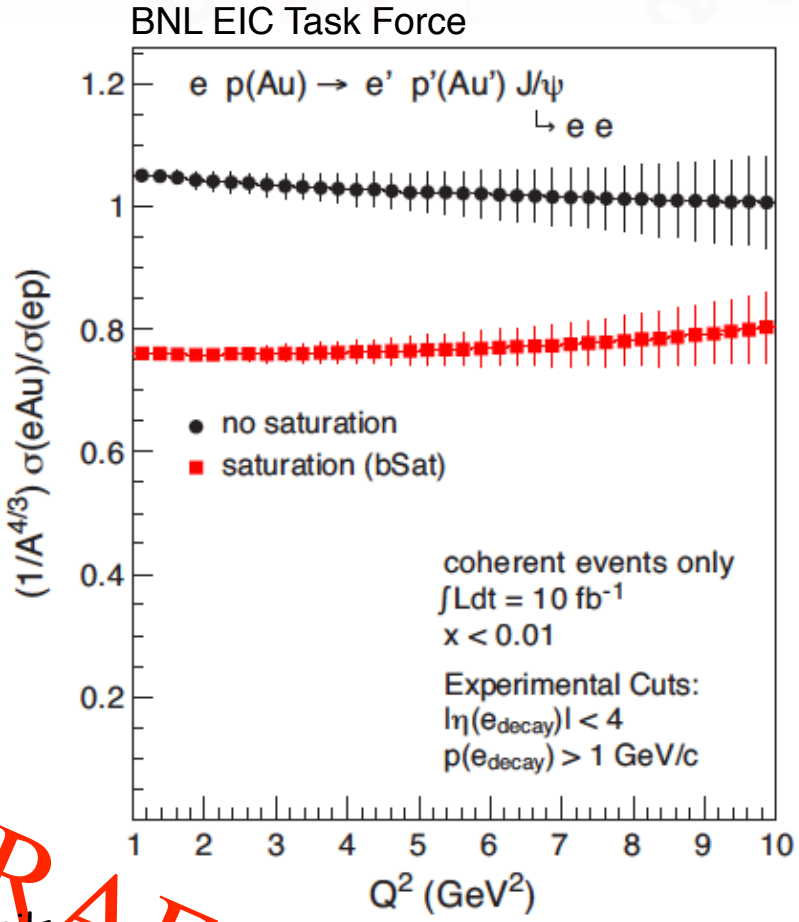
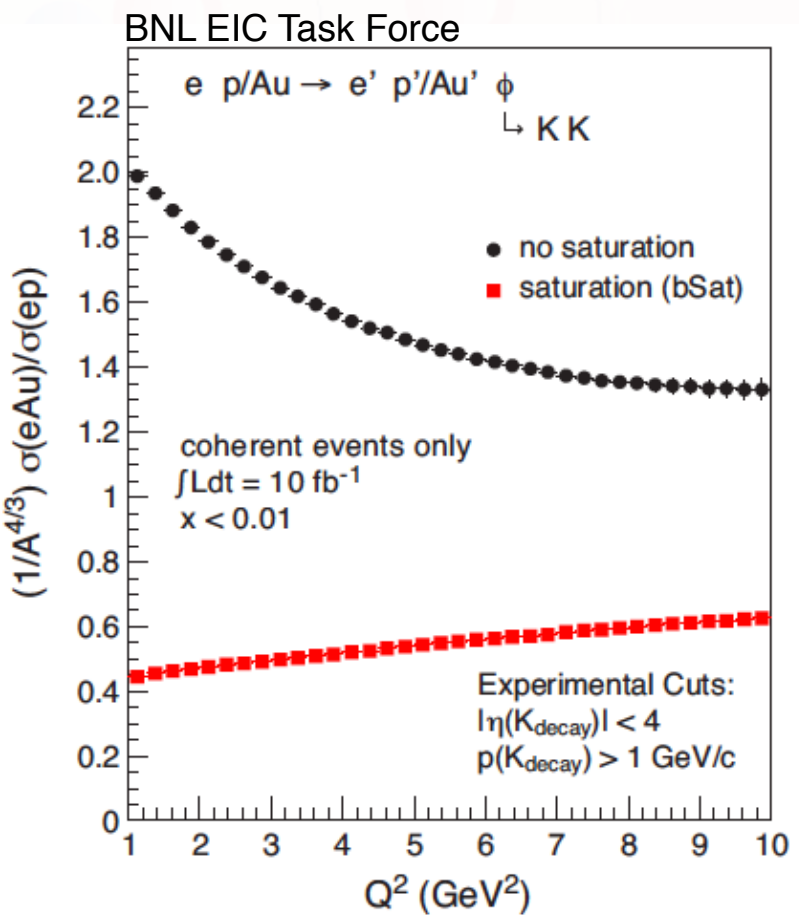
Future Opportunities: Unpolarized eA physics

- Diffractive VM production at EIC: J/Ψ and Φ (2)





DRAFT

- Details

Summary and Outlook

- Status and Concepts
  - HERA: Precision structure function measurements (F_2) at low x
  - At low Q^2 and low x: DGLAP (Leading twist) approach leads to valence-like gluon behavior
  - Diffraction: Important contribution to overall ep event yield
  - Dipole model: Allows to describe inclusive and diffractive measurements. Reach of saturation region at low x not conclusive
  - Lesson: Optimize any future EIC efforts for acceptance and luminosity
  - eA: No information in low-x region
  - dAu results at RHIC: Can saturation account for observed behavior? Complementary probes important (RHIC/LHC)!
  - Important constrain on gluon polarization at medium and higher x from semi-inclusive polarized DIS and RHIC-SPIN program (Hint for $\Delta G \neq 0$) - Complementary to EIC

Summary and Outlook

- Future Opportunities
  - EIC: First polarized ep collider - Precision measurement of polarized gluon distribution at low-x and quark flavor structure
  - EIC will allow to study the physics of strong color fields
  - Required: EIC at high luminosity and optimized detector
  - EIC will allow to bridge several QCD communities (Hadron structure and Relativistic Heavy-Ion)